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The Effect of Audio and Tactile Cues on Soldier Decision Making and Navigation in Complex Simulation Scenarios

by Douglas S. Savick, Linda R. Elliott, Orest Zubal, and Christopher Stachowiak

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Human Research and Engineering Directorate, ARL

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14. ABSTRACT
Human factors studies of an array of military operation roles have shown significant overloading of the visual channel during the execution of many Soldier tasks, such as navigation and target detection (Mitchell, Samms, Glumm, Krausman, Brelsford, & Garrett, 2004). The objective of this study was to assess the effectiveness of tactile and three-dimensional (3-D) auditory cues to reduce overall workload and response time during high-visual workload target acquisition and robot navigation tasks. Soldiers performed target acquisition and navigation tasks in a computer-based simulation of Army target acquisition and navigation of robotic resources. Within this simulation (Operation Flashpoint), the participant functioned as the vehicle's commander/gunner. At pre-determined intervals, semi-autonomous robots called for help and directions. The call for help occurred three different ways: a) visual indication, b) 3-D audio alert, and c) tactile alert. Results indicate that the mean response time in the tactile condition was significantly lower than in the audio or visual conditions. There was no significant difference between audio and visual conditions. Ratings of the National Aeronautics and Space Administration Task Load Index workload were lowest for tactile and highest for the 3-D audio condition.

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Contents

List of Figures v

List of Tables v

Acknowledgments vi

1. Background 1

2. Objective 3

3. Methodology 3

3.1 Participants 3

3.2 Instrumentation....3

3.2.1 Study Location 3

3.2.2 Equipment and Software 4

3.3 Target Acquisition Task 5

3.4 Robotic Vehicle Control Task....6

3.4.1 Visual Presentation....7

3.4.2 Auditory Presentation....7

3.4.3 Tactile Presentation 8

3.5 Procedures 8

3.5.1 Training 8

3.5.2 Experimental Design 9

4. Results 10

4.1 Participants' Results....10

4.2 Accuracy Results....10

4.3 Response Time Results 11

4.4 NASA TLX Index Rating Results....12

4.4.1 Mental Demand 12

4.4.2 Physical Demand....13

4.4.3 Temporal Demand....13

4.4.4 Performance....14

4.4.5 Effort 14
4.4.6 Frustration 15

5. Discussion **15**

6. Recommendations **16**

7. References **18**

Appendix A. Volunteer Agreement Affidavit **21**

Appendix B. Demographic Questionnaire **21**

Appendix C. Vehicles' Paths **27**

Appendix D. Command Screen **29**

Appendix E. NASA TLX Rating Scale and Definitions **31**

Appendix F. Results of the Demographic Questionnaire **33**

Appendix G. Results of the NASA TLX Questionnaire **35**

Distribution List **36**

List of Figures

Figure 1. Operator station. 4
Figure 2. Tactile belt. 5
Figure 3. Operation Flashpoint screen. 6
Figure 4. Map screen showing robotic vehicle courses and control buttons. 7

List of Tables

Table 1. Order of modality presentation. 10
Table 2. General demographic results. 10
Table 3. Mean direction accuracy by display. 11
Table 4. Mean direction accuracy by roster (Soldier). 11
Table 5. Mean, standard error, and confidence intervals for response time by display modalities 12
Table 6. Pair-wise comparisons of response time by display. 12
Table 7. Mean ratings for mental demand by display. 13
Table 8. Paired comparisons for mental demand. 13
Table 9. Mean ratings for physical demand by display. 13
Table 10. Mean ratings for temporal demand by display. 13
Table 11. Paired comparisons for temporal demand. 14
Table 12. Mean ratings for performance by display. 14
Table 13. Mean ratings for effort by display. 14
Table 14. Paired comparisons for effort. 14
Table 15. Mean ratings for frustration by display 15
Table 16. Paired comparisons for frustration. 15
Table G-1. NASA TLX ratings of the different systems 35

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1. Background

This effort was conducted as part of the Army Technology Objective (ATO) for Enhanced Unit of Action Maneuver Team Situational Understanding (SU), sponsored by the U.S. Army Research Laboratory (ARL). The intent of the SU ATO is to demonstrate information system interfaces that will improve Soldier SU, decision making, and mission planning.

Military operations now have unprecedented information flow to execute action. Although technology provides ever-increasing sources of information, there is abundant literature regarding limitations of human information processing and resulting error in information interpretation and decision making because of overload. In the military, technology that involves information fusion, battlefield visualization, and intelligent decision-aiding technologies addresses many of these issues. Still, the demand for information processing increases at all levels, from the operator to the commander.

Human factors studies of an array of military operation roles have shown significant overloading of the visual channel during the execution of many individual and multiple tasks (Mitchell, Samms, Glumm, Krausman, Brelsford, & Garrett, 2004). The demand for focal visual attention diminishes the capacity for task sharing and attention allocation, especially in the context of unexpected changes and events. If other sensory modalities can be effectively used in a military environment, the benefit could be significant in increasing survivability, information flow, and mission achievement.

Three-dimensional (3-D) audio cues are investigated in this study for use as direction cues to the operator and are compared to the use of tactile cues. The use of auditory cues in providing spatial information about direction or location has not been adequately explored. For the most part, research on spatialized audio has been focused on use in aircraft to support listeners who monitor multiple radio communications, allowing them to selectively attend to one message at a time when messages are presented in different spatial locations (McKinley, Erickson, & D'Angelow, 1994; Glumm, Kehring, & White, 2006, 2007). In these studies, dismounted Soldiers (Haas, dePontbriand, Mello, Patton, & Solounias, 2000) and helicopter pilots (Haas, Gainer, Wightman, Couch, & Shilling, 1997) identified and responded to multi-channel radio communications more quickly and accurately with 3-D audio than with existing monaural displays. In addition, spatial information about target location has been found to have positive effects on target acquisition performance and perceptions of workload. In one study, commercial airline crew members acquired targets faster using a 3-D audio display than did crew members using a one-earpiece headset; however, no significant differences were found between these auditory displays in the number of targets acquired (Begault, 1993). In other investigations, 3-D audio cues alone did not improve target localization, but when paired with visual cues, the 3-D cues resulted in improvements in time and accuracy, reduced head movement, and lower subjective ratings of workload

(McKinley et al., 1995; Tannen, 2001). Glumm, Kehring, and White (2007) reported that adding 3-D audio and tactile cues to a visual cue resulted in faster time to slew, time to first shot, and a higher percentage of target hits. These studies show some promise for 3-D audio cues for direction cues, and therefore, in this study, 3-D audio cues are used and evaluated for effectiveness as direction cues in a multimodal multi-task situation.

Tactile interfaces also provide an additional sensory channel for the receipt of information through vibro-tactile means. A common example is the vibration mode in cell phones and pagers. More complex tactile interfaces use patterns of vibratory feedback through the placement of multiple vibrating tactors[1]. Although the sense of feel is not typically used as a communication channel, researchers are now realizing the high potential it represents. An intuitive organization of vibro-tactile stimuli can portray complex and dynamic patterns and has been shown to be effective in numerous situations (Van Erp, 2005).

Tactile displays have been shown to reduce overall workload when the design of the display is easy to interpret, intuitive, and can convey information without diverting the user's attention away from the operational task at hand. In military applications, tactile displays have provided improved situational awareness to operators of high performance weapon platforms and have improved their ability to spatially track targets and sources of information. Tactile interface solutions have also proved effective for pilot orientation and navigation in sea, land, and air (Carlander & Eriksson, 2006; Calhoun, Draper, Ruff, Fontejon, & Guilfoos, 2003; Calhoun, Fontejon, Draper, Ruff, & Guilfoos, 2004; Chiasson, McGrath, & Rupert, 2003; Dobbins & Samways, 2002, 2003; van Erp & van Veen, 2003, 2004; van Erp, Veltman, van Veen, & Oving, 2003). Underlying principles regarding tactile display and workload have also been investigated in more controlled lab studies with the use of synthetic tasks (Cholewiak, Brill, & Schwab, 2004; Lindeman, Yanagida, Sibert, & Lavine, 2003; Moorhead, Holmes, & Furnell, 2004; Sarter, 2001, 2002).

Although tactile interface solutions have demonstrated effectiveness in a range of applications, one should not assume that effectiveness will generalize across all situations. Successful implementation of tactile displays lies first in "front end[2]" analyses of the operator cognitive and task demands. Tactile displays should be considered when other sensory channels are overwhelmed with information, if other channels are diminished (e.g., poor visibility, high noise, fatigue, etc.) (Van Erp, 2005), and as a complementary channel to visual display during multi-task and high workload situations (Coovert et al., 2006). A principled approach is needed to identify opportunities where tactile cues are likely to alleviate workload and enhance performance. Wickens' multiple resource theory (2002) provides such guidelines for the reduction of cognitive load through distribution of tasks and information across various sensory channels.

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[1]Direct current motors (electromechanical transducers), also called tactors, are often used for vibrotactile devices.
[2]A front end analysis is the first step in a design process.

2. Objective

The objective of this study was to assess the effectiveness of tactile and 3-D auditory cues to reduce overall workload and response time during high visual workload target acquisition and robot navigation tasks.

3. Methodology

3.1 Participants

Ten male Soldiers from Fort Knox, Kentucky, agreed to participate in this study. Demographic data are provided in appendix A.

3.2 Instrumentation

Soldiers performed target acquisition and navigation tasks in a computer-based simulation of Army target acquisition and navigation of robotic resources, as described next.

The National Aeronautics and Space Administration (NASA) Task Load Index (TLX) was used to assess the participants' experience of workload (Hart & Staveland, 1988). This technique uses rating scales to assess mental, physical, and temporal demands, performance, effort, and frustration. Initially, each of these six workload factors is assigned a weight, based on the responses of the participant to pair-wise comparisons. In these comparisons, the six factors are presented in 15 possible pairs, and for each pair, the participant is asked to indicate the factor that s/he perceived contributed most to his or her workload experience. The participant then completes rating scales that provide a measure of the magnitude of the workload for each factor. Those factors perceived by the participant to have contributed most to his or her workload experience are given more weight in the computation of an overall workload score.

3.2.1 Study Location

The study was performed in an indoor laboratory space, during ideal office ventilation and lighting conditions. Two computers, placed at about a 90-degree angle, were running at a workspace, as seen in figure 1. From the chair, the participants could swivel to face one computer or the other.

Figure 1. Operator station.

3.2.2 Equipment and Software

The two computers used were each a Dell[3] OptiPlex[1] 400 with 1.7-Ghz Pentium[4] 4 processors and 512 Mb of memory. The imagery was presented on two 19-inch Dell flat screen cathode ray tube monitors. Controls were standard Dell mice and keyboards. Sennheiser[5] HD280 Pro earphones were used to receive auditory information. A Bluetooth[6] was used to deliver information to the Massachusetts Institute of Technology (MIT) wireless tactile control unit (WTCU).

The WTCU was developed at MIT under the Advanced Decision Architectures Collaborative Technology Alliance (ADA CTA). The tactile sensors were commercial off-the-shelf inertial shaker motors that used the same DC "pancake" motor as is present in cell phones. The tactors on the WCTU system were manufactured to vibrate at 80 Hz. Each signal consisted of one tactor vibrating for 500 ms. Each tactor was sealed with glue and then molded in a plastic block 18.4 mm long, 17 mm wide, and 6 mm thick. The plastic encasement was designed to make the motor more robust and increase the contact area between the motor and the skin. For this experiment, the system was configured to be worn around the waist with eight tactors at the eight map cardinal point positions around the Soldiers' waists. The control unit received wireless signals from a lap-top and converted them into recognizable patterns of vibration. The tactile display was powered by a 9-volt battery or a rechargeable 7.2-volt lithium-ion battery. The tactile belt was fitted to each participant to accommodate individual waist sizes. The belt was secured under the participant's rib

[3]Dell and OptiPlex are trademarks of Dell Corporation.
[4]Pentium is a registered trademark of Intel Corporation.
[5]Sennheiser is a trademark of Sennheiser Electronic GmbH & Co. KG.
[6]The Bluetooth word mark and logo are registered trademarks owned by the Bluetooth SIG, Inc.

cage over top of the undershirt. The vibrating tactors were then placed to consistently correspond to compass points.

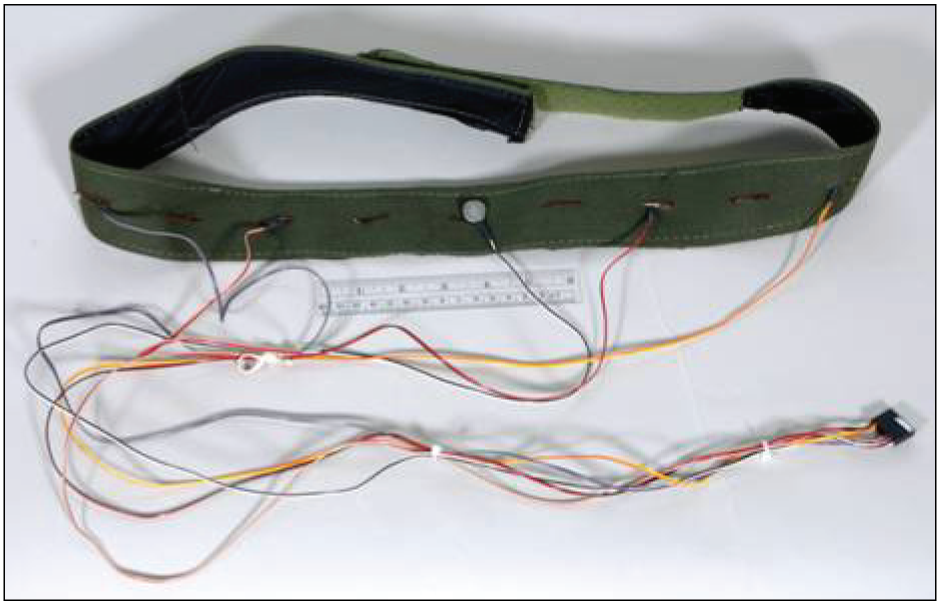

Figure 2. Tactile belt.

Two software packages were used during this study. The first is the war game software Operation Flashpoint[7], Game of the Year edition. Operation Flashpoint was used in a mode where it required the participant to acquire and destroy enemy targets. The second software package was custom software, written in house at ARL to provide the stimulus and data collection for the experiment. The stimulus was a simulation of supervisory control of three robotic vehicles. The software recorded all time and error data to a file format easily importable to Microsoft Office Excel[8] and the statistics software package SPSS[9].

3.3 Target Acquisition Task

One computer system was set up to present an interactive target acquisition and engagement task based on the game Operation Flashpoint. Within this war game, the participant functioned as the vehicle's commander/gunner. The participant looked at the computer screen to see the area around the moving tank from the perspective of the turret in open-hatch mode. His task was to scan the terrain, using the computer mouse to pan his view, and fire at targets as they became available. The driving function was performed by the computer following a pre-programmed course through complex simulated terrain. At pre-determined intervals, the robots called for help and the operator responded by indicating which direction the robot was to move. The call for help occurred three different ways: a) visual indication, b) 3-D audio alert, and c) tactile alert. Figure 3 presents a

[7]Operation Flashpoint is a trademark of Codemasters and Bohemia Interactive Studio.
[8]Excel is a trademark of Microsoft Corporation.
[9]SPSS (Statistical Package for the Social Sciences) is a registered trademark of SPSS, Inc.

sample operator screen view. The mission scenario was structured to create a high-workload context for operations.

Figure 3. Operation Flashpoint screen.

3.4 Robotic Vehicle Control Task

A map displaying the location of three simulated robotic vehicles was presented on a second computer system (see figure 4). The remote vehicle paths, with identified waypoints, were displayed on a topographic background on the screen. As a vehicle reached a waypoint, it issued a request to the participant to provide directional guidance so that it could reach the next waypoint. For this study, vehicle movement in the reverse direction was not an objective. Commands to move the remote vehicle did not include the southwest (SW), south (S), and southeast (SE) directions.

The participant, acting as the vehicle commander/gunner, used the topographic map to identify the requesting vehicle, identify the waypoint at which the requestor was situated, and determine the compass direction that the vehicle needed to take from its present location to reach its next designated waypoint. An associated screen on the topographic map was cursor activated and allowed the participant to specify compass travel direction and send that order to the requesting vehicle.

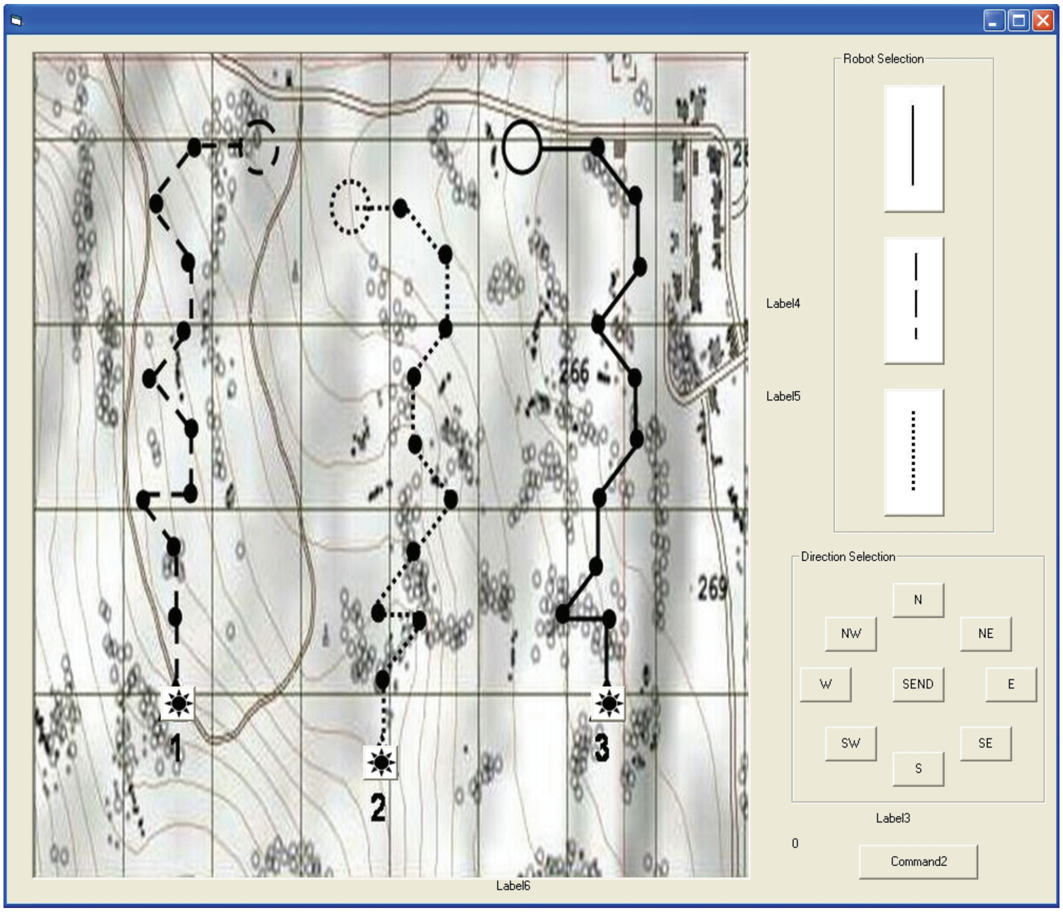

Figure 4. Map screen showing robotic vehicle courses and control buttons.

3.4.1 Visual Presentation

In the visual information mode, the participant was first notified that a robot needed assistance by an auditory message through his headphones saying “robot needs help”. He looked at the computer with the topographic map display and noted that one of the icons in the upper right corner (marked “robot selection”) was blinking. The participant hit the blinking button, assuming control of the robot whose course matched that icon. The course of each icon was indicated by a different type of line (i.e., continuous, broken, or dotted). The blinking icon indicated which robot was concerned, and then the participant located that particular robot. Based on the location of the robot on the map, the participant looked to see in which direction to turn the robot to approach the next waypoint. Using the “direction selection” control on the bottom left of the screen, he selected the direction for the robot to move to reach the next waypoint. This condition was a baseline, with the map information being available in all modes.

3.4.2 Auditory Presentation

Auditory information was presented via the Sennheiser headphones. The sounds heard in the experiment were pre-recorded verbal alerts spoken by a female voice played as sound (wav) files on the computer. The alerts were digitally pre-recorded sound files of a female talker made in a

sound-treated room. We spatialized these sound files by playing them through a 3-D VALS[10] audio sound engine to make them sound as if they were occurring at different spatial locations. The spatialization used generic head-related transfer functions developed by the U.S. Air Force. The headphones were used to allow for communication between the controller and participant and to present auditory cues. The auditory cues were presented with the use of 3-D audio software, allowing the cue to be directional in a plane 360 degrees around the participant's head. The participant was trained to decode the apparent orientation of the auditory source around his head into the desired compass direction (again, north was front, west left, east right, etc.) to be taken by the requesting vehicle to reach its next waypoint. Selecting the robot and entering the direction to the next waypoint were the same as with the preceding mode.

3.4.3 Tactile Presentation

Tactile information was presented by a belt-like system, shown in figure 4, that was worn by the participant around his waist. Instead of the verbal cue used in visual mode, the participant was cued that a robot needed assistance by one of the tactors on the belt vibrating. The participant was trained to decode location of vibration on the belt into a compass direction (north was front, west left, east right, etc.) that the requesting vehicle was to take to reach its next waypoint. Selecting the robot to control and entering the robot's direction to the next waypoint were the same as in visual mode.

3.5 Procedures

When a prospective participant arrived at the test site, he was provided with the volunteer agreement affidavit (see appendix B), and the entire testing process was explained. Any questions he had were answered.

3.5.1 Training

After the volunteer agreement affidavit had been read and signed, training in the primary and secondary tasks began. The participant was familiarized with the NASA TLX and the target acquisition task. After the participant was comfortable with the target acquisition task, training in the robotic vehicle control task began. The participant was trained in the procedure for each display mode, tested on that mode, and trained in the next mode.

The training was conducted for two operational tasks: a) navigation though the Operation Flashpoint war game and b) conducting a robotic navigation task. First, the participant was familiarized with the Operation Flashpoint war game. He was given instructions for controlling his turret, looking for targets, and firing the defensive weapon. He was allowed several practice runs until he indicated that he was familiar with the game controls and felt comfortable, efficient, and effective in using the controls. Training time was approximately 30 minutes for the basic game familiariza-

[10]VALS, which stands for virtual auditory localization system, is a registered trademark of Veridian Engineering.

tion; however, if the participant requested more time for practice, he was given it. Short rest periods were provided between practice runs.

The training for the robotic navigation task included three different information display conditions. For each modality presentation, the participant wore the earphones to alert him of a request from a robot to direct it to the next waypoint. Additionally, the map for each robot's path was also present for each modality presentation. The participant was trained in using each modality before the corresponding experiment test run that used that modality.

For training the visual phase, the sequence of events was demonstrated for the participant. He started the trial by engaging in the war game. While he was engaged in the war game, a call for guidance from one of his vehicle's (paths) was issued in his headset. He was shown on the topographical scene screen, which included vehicle paths and the command screen (appendices C and D), how to identify which vehicle (path) was asking for direction, how to locate the path and identify at which waypoint the vehicle was located. Then he was shown how to determine which compass direction the vehicle was to travel to reach the next waypoint. Finally, he was shown how to designate the compass direction on the command screen and send that command.

Training for the auditory phase was similar to the tactile phase. An auditory call through the headset for directional guidance came from one of his vehicle's (paths). The participant was taught to correlate the location of an audio cue to compass points. The audio cues were two-dimensional, appearing to emanate around the participant's head without an elevation component. Thus, the participant used audio cues' emanation to form and send direction commands to the requesting vehicle (path). Training for this phase ended when the participant and the investigator agreed that the participant understood the scenario and could perform effectively.

For the tactile training phase, the tactile belt was fitted to each participant. Training began with the Soldier engaging in the war game. An auditory call through the headset for directional guidance came from one of his vehicle's (paths). At the same time, one of the devices in his belt was vibrating. The participant was taught to correlate that vibrating spot with a direction of the compass. He then could go directly to his command screen, identify the calling vehicle (path), translate the belt vibration to a compass direction and send that command. Training for this phase concluded when the participant and the investigator agreed that the participant understood the scenario and could perform effectively. A short break was given before each test run began.

The participant was also familiarized with the NASA TLX and was instructed how to answer the NASA TLX that was issued after each test run. Training for this phase concluded when the participant and the investigator agreed that the participant understood the scenario and could perform effectively. A short break was provided before the test run began.

3.5.2 Experimental Design

Each participant was presented with a certain modality, based on the presentation order shown in table 1.

Table 1. Order of modality presentation.

Participant Number	Modality Order
1, 7	A, B, C
2, 8	B, C, A
3, 9	C, A, B
4, 10	A, C, B
5,	B, A, C
6,	C, B, A

A = visual; B = auditory; C = tactile

After the test phase was selected, one computer system's screen presented the participant with a driving scene and occasional advances of "enemy" attacks. Within this scenario, the vehicle under control advanced, and the participant had to determine which vehicle was calling, where the vehicle was located, and the direction the vehicle had to take to reach its next destination point. After the test portion was completed, when all the vehicles arrived at their destinations, the participant was asked to rate the experience on the NASA TLX scale. Then he was provided with a rest before proceeding to the next test condition.

4. Results

4.1 Participants' Results

The general demographic data for the participants are presented in appendix A. A partial analysis of some of the demographic data provided the average age, time in service, and time in rank. The results are presented in table 2. The participants' ages ranged from 20 to 39 years old. Their military experience ranged from 1 to 13 years. The group consisted of one E4 (Specialist), five E5s (Sergeant), and four E6s (Staff Sergeant); all were right handed and four required glasses.

Table 2. General demographic results.

Demographic	Mean	SD[a]
Age (years)	28.2	5.45
Time in service (years)	7.6	4.48
Time in Rank (years)	3.2	3.43

SD = standard deviation

4.2 Accuracy Results

First, results were checked with regard to the extent that Soldiers clicked on the correct robot in response to requests for assistance. In fact, Soldiers consistently clicked on the correct robot, regardless of display condition, with a mean overall accuracy of 0.998.

Soldiers also indicated the direction for robot movement in response to requests for assistance. In this decision event, Soldiers could err by (a) not responding or (b) providing the wrong direction.

Soldiers did not have to refer to SW or S directions. Again, the incident of error was very small. Non-responses were rare (less than 1% of total responses, evenly distributed across display conditions). Table 3 provides mean differences of total direction error by display. Tactile display had the highest accuracy (96% correct response), then visual (95% correct response), then audio (94%). More of the variance in response accuracy was attributable to differences among Soldiers, as seen in table 4.

Table 3. Mean direction accuracy by display.

Display	Mean	SD	N
Audio	0.94	0.23	300
Tactile	0.96	0.18	300
Visual	0.95	0.21	300

Table 4. Mean direction accuracy by roster (Soldier).

Roster	Mean	SD	N
1.00	0.98	0.10	90
2.00	0.92	0.26	90
3.00	0.91	0.28	90
4.00	0.98	0.10	90
5.00	0.96	0.18	90
6.00	0.97	0.14	90
7.00	0.94	0.23	90
8.00	0.92	0.26	90
9.00	0.95	0.20	90
10.00	0.94	0.23	90
Total	0.95	0.21	900

The results of analyses of variance (ANOVAs) of response accuracy indicate no significant effect because of display condition (F 2, 18 = 0.31; $p = 0.73$) or variance among Soldiers (F 9,18 = 0.72, $p = 0.69$); however, they did indicate an interaction between display and Soldier (F 2,18 = 2.27; $p = 0.02$) so that the pattern of display effects differ for different Soldiers.

4.3 Response Time Results

The results of the response times during the presentation of different methodologies are shown in table 5. The visual display modality was the baseline condition. Contrary to expectations, adding the audio cue actually increased response time. Adding the tactile cues resulted in lower mean response times.

Data were analyzed with univariate ANOVA, within-subjects analysis of response time by display. Results indicate significant differences attributable to display modality (F 2, 18 = 7.7; $p = 0.004$), differences among Soldiers, and a Display x Roster interaction. Partial η^2 indicates strong effect size (0.46). Also, results indicate a significant effect because of differences among Soldiers (F

9,18 = 4.45, *p* = 0.003, partial η^2 = 0.69) and a smaller but significant Display x Soldier interaction (F 2, 18 = 3.49; *p* = 0.00; partial η^2 = 0.07).

Table 5. Mean, standard error, and confidence intervals for response time by display modalities

Display	**Mean**	**Standard Error**	**95% Confidence Interval**	
			Lower Bound	Upper Bound
Visual	6.480	.113	6.259	6.702
Audio	6.593	.113	6.371	6.815
Tactile	5.524	.113	5.302	5.747

Post hoc pair-wise comparisons are provided in table 6. Results indicate that the mean response time in the tactile condition was significantly lower than in the audio or visual conditions. There was no significant difference between audio and visual conditions.

Table 6. Pair-wise comparisons of response time by display.

(I) Display	**(J) Display**	**Mean Difference (I-J)**	**Standard Error**	**Sig.**	**95% Confidence Interval for Difference**	
					Lower Bound	**Upper Bound**
Audio	Tactile	1.069(*)	.160	.000	.754	1.383
	Visual	.113	.160	.482	-.201	.427
Tactile	Audio	-1.069(*)	.160	.000	-1.383	-.754
	Visual	-.956(*)	.160	.000	-1.270	-.642
Visual	Audio	-.113	.160	.482	-.427	.201
	Tactile	.956(*)	.160	.000	.642	1.270

*The mean difference is significant at the .05 level.

4.4 NASA TLX Index Rating Results

Soldiers gave direct ratings of mental demand, physical demand, temporal demand, performance demand, effort, and frustration (Hart & Staveland, 1988). Definitions for these aspects provided to Soldiers are provided in appendix E. Comparisons were made independently for each aspect of workload (e.g., mental demand, physical demand, temporal demand, performance, and effort). Ratings were analyzed with a repeated measures ANOVA.

4.4.1 Mental Demand

Mean ratings of mental demand are provided in table 7. Ratings were lowest for tactile and highest for the audio condition. ANOVA results indicate that differences among display conditions were significant (F 2, 18 = 7.56; *p* = 0.004; partial η^2 = 0.4567). Results of paired comparisons are provided in table 8. Using Holmes Bonferonni criteria for *post hoc* comparisons, we see that the audio condition is significantly lower than tactile. However, there was no significant difference between visual and other conditions.

Table 7. Mean ratings for mental demand by display.

	Mean	SD	N
Visual	5.20	2.75	10
Audio	6.55	1.92	10
Tactile	3.80	1.96	10

Table 8. Paired comparisons for mental demand.

Mental Demand	t	df	Sig. (2-tailed)
Visual versus Audio	-2.419	9	.039
Audio versus Tactile	3.884	9	.004
Visual versus Tactile	1.688	9	.126

4.4.2 Physical Demand

Table 9 provides mean ratings for physical demand. A repeated measures ANOVA shows that differences are not significant (F 2, 18 = 0.22; p = 0.80; partial η^2 = 0.02).

Table 9. Mean ratings for physical demand by display.

	Mean	SD	N
Visual	2.95	3.18	10
Audio	3.15	2.82	10
Tactile	2.65	2.26	10

4.4.3 Temporal Demand

Table 10 provides mean ratings for temporal demand. Ratings were lowest for tactile condition and highest for audio condition. These differences were found to be significant (F 2, 18 = 5.09; p = 0.02; η = 0.36). Results of paired comparisons are provided in table 11. Using Holmes Bonferonni criteria for *post hoc* comparisons to control for family-wise error, we see that the audio condition is significantly lower than the tactile condition. However, there was no significant difference between visual and other conditions.

Table 10. Mean ratings for temporal demand by display.

	Mean	SD	N
Visual	4.85	2.57	10
Audio	5.55	1.96	10
Tactile	3.30	1.82	10

Table 11. Paired comparisons for temporal demand.

Temporal Demand	**t**	**df**	**Sig. (2-tailed)**
Visual versus Audio	-1.326	9	.218
Audio versus Tactile	3.126	9	.012
Visual versus Tactile	1.774	9	.110

4.4.4 Performance

Performance is not a rating of workload demand per se; rather, it reflects a self-assessment of performance (see appendix E for definitions). Here, ratings were highest for the tactile condition and lowest for the visual. ANOVAs indicate that these differences are not significant (F 2, 18 = 0.52; p = 0.60; η = 0.05).

Table 12. Mean ratings for performance by display.

	Mean	**SD**	**N**
Visual	4.70	2.54	10
Audio	5.00	2.17	10
Tactile	5.50	2.88	10

4.4.5 Effort

Mean ratings for effort for each display condition are provided in table 13. The tactile condition had the lowest mean rating, while the highest mean ratings were from the audio condition. ANOVAs indicate that these differences were significant (F 2, 18 = 4.15; p = 0.03; η = 0.316). Paired comparisons show (table 14) that differences were significant between tactile and audio; differences between visual and other conditions were not significant.

Table 13. Mean ratings for effort by display.

	Mean	**SD**	**N**
Visual	5.25	2.23	10
Audio	5.95	2.25	10
Tactile	3.75	2.15	10

Table 14. Paired comparisons for effort.

Effort	**t**	**df**	**Sig. (2-tailed)**
Visual versus Audio	-1.313	9	.222
Audio versus Tactile	2.659	9	.026
Visual versus Tactile	1.622	9	.139

4.4.6 Frustration

Mean ratings for frustration for each display condition are provided in table 15. The tactile condition had the lowest mean rating, while highest mean ratings were from the visual condition. ANOVAs indicate that these differences were significant ($F_{2, 18} = 4.57$; $p = 0.025$; $\eta = 0.337$). Paired comparisons show (table 16) that differences were significant between tactile and audio; differences between visual and other conditions were not significant.

Table 15. Mean ratings for frustration by display.

	Mean	**SD**	**N**
Visual	5.25	2.23	10
Audio	5.95	2.25	10
Tactile	3.75	2.15	10

Table 16. Paired comparisons for frustration.

Frustration	**t**	**df**	**Sig. (2-tailed)**
Visual versus Audio	-1.313	9	.222
Audio versus Tactile	2.659	9	.026
Visual versus Tactile	1.622	9	.139

5. Discussion

This study demonstrates effectiveness of tactile cues in a complex and dynamic decision-making scenario. The results indicate that the addition of tactile cues to visual cues was quite effective in this situation, relative to the addition of audio cues and to visual cues alone. Although differences in operator accuracy were not significant (all conditions were associated with high accuracy), there was a significant interaction between display condition and individual, with regard to accuracy, so that some participants were more accurate with the tactile cues, while others were more accurate in other cue conditions. Further research is needed in order to identify and explain this moderating effect.

The addition of tactile cues to the visual cues was associated with faster response times, while the addition of audio cues was associated with longer response times. *Post hoc* comparisons showed that the tactile (plus visual) condition was associated with faster response times than audio (plus visual) and the unimodal visual cue conditions. There was also a significant interaction with individuals, indicating that display effects can be different, depending on individual differences. This interaction raises the question as to which individual differences might be important moderators with regard to display effects and display design.

One possible reason for the results regarding effectiveness of 3-D audio cues may be that the 3-D audio system was basically “one size fits all”; 3-D audio is most effective when tailored to each individual. It is likely that individuals differed in the degree to which they could accurately perceive 3-D localizations. This could explain why the 3-D audio condition was more variable and less effective than other conditions. 3-D audio cues have been used effectively for target localization in Air Force pilot situations (Tannen, 2001) and some other target localization tasks with limited success (Glumm, Kehring, & White, 2007). Another limitation for 3-D audio for the purpose of target localization is the front-rear confusion that often occurs. The addition of tactile cues to 3-D audio direction cues would resolve this, as would the addition of spatial language (e.g., target at 1 o’clock, etc).

The addition of tactile cues was also associated with lower ratings of workload compared to the addition of audio cues. Tactile cues were associated with lower mental demand, lower temporal demand, lower frustration, and lower effort. Within each subject, there was correspondence between ratings of workload and response time. However, correlations between response time and workload ratings, when calculated across all subjects, were not significant. This is likely because of the differences among subjects in how they used the workload rating scales. That is, a rating of “5” is likely not equivalent across different subjects; workload ratings are thus more interpretable when the ratings are “within person”.

6. Recommendations

There is a high probability that the next generation of battle command systems will create visual and cognitive overload in the Soldier (Mitchell et al., 2004). Several ARL studies are focused on the utility of tactile and/or audio displays for various Army operator roles, with promising results for tasks such as land navigation, covert communications, and communication alerts (Elliott, Redden, Krausman, Carstens, 2005). A review of these and other studies shows that 3-D audio and tactile cues vary in degree of effectiveness, depending on the nature of the display and the purpose for which it is used (e.g., alerts, communication, direction cues) (Coovert et al., 2006; Redden & Elliott, 2007). Recent studies indicate that multimodal displays have potential to enhance operator performance. One potential advantage to designing redundancy is that in case environmental noise or vibration masks the auditory or tactile portion of the cues or demanding visual tasks interfere with the operator’s ability to see a visual cue, the operator could still rely on an alternate modality. A study was conducted to examine the effects of alerts on platoon leader performance and decision making. Tactical information was presented to a platoon leader on a visual display. One uni-modal and two multi-modal alerts (visual, visual and auditory, visual and tactile) were used. Response times for the visual alert alone were 63% slower when compared to both the visual and auditory and visual and tactile alerts (Krausman, Pettitt, & Elliott, 2007).

This study indicates potential effectiveness of a multi-modal display design with tactile and visual cues and is part of an ongoing series of studies to ascertain principles of display modality that can be used to refine task and workload analyses, performance models, and ultimately result in improved displays to reduce workload and support warfighter decision making and performance.

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Appendix A. Demographic Questionnaire

DATE_____________ **ID#______**

DEMOGRAPHIC and EXPERIENCE FORM

1. Date of Birth (YYYY-MM-DD) ___________________
2. Time in Service Years_________ Months__________
3. Rank ____________ Time in Rank Years__________ Months _________
4. Primary MOS ____________ Time in MOS Years_________ Months ________
5. Secondary MOS ____________
6. Duty Position/Title ____
7. Time in position Years_______ Months________
8. Are you (circle) Left Handed Right Handed
9. What is your waist size ___________?
10. Do you wear glasses/contact Yes_____ No_____
11. Do you use a computer at Work_____ Home_____ Both_____
12. Do you play computer games Yes_____ No______

    If No, go to Question 13

    12a. Estimate time playing computer games per day _________________

    12b. When playing, do you use Mouse_____

    Keyboard_____

    Joystick_____

    Other____ Specify_________________

13. Vehicle Experience & Crew Positions you have had (Check all that apply)

	Commander	Gunner	Loader	Driver
Bradley Fighting Vehicle	[ ]	[ ]	[ ]	[ ]
M1 Tank	[ ]	[ ]	[ ]	[ ]
Other (Please Specify)___________	[ ]	[ ]	[ ]	[ ]
_________________________________	[ ]	[ ]	[ ]	[ ]

14. Education level (circle) GED High School Some College

Bachelor Degree Masters Degree Ph.D. Degree Other>Specify____________

Any specialty civilian/military training you received_______________________

____

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Appendix B. Volunteer Agreement Affidavit

TID#______

VOLUNTEER AGREEMENT AFFIDAVIT:

ARL-HRED Local Adaptation of DA Form 5303-R. For use of this form, see AR 70-25 or AR 40-38

The proponent for this research is:	**U.S. Army Research Laboratory Human Research and Engineering Directorate Aberdeen Proving Ground, MD 21005**

Authority:	Privacy Act of 1974, 10 U.S.C. 3013, [Subject to the authority, direction, and control of the Secretary of Defense and subject to the provisions of chapter 6 of this title, the Secretary of the Army is responsible for, and has the authority necessary to conduct, all affairs of the Department of the Army, including the following functions: (4) Equipping (including research and development), 44 U.S.C. 3101 [The head of each Federal agency shall make and preserve records containing adequate and proper documentation of the organization, functions, policies, decisions, procedures, and essential transactions of the agency and designed to furnish the information necessary to protect the legal and financial rights of the Government and of persons directly affected by the agency's activities]
Principal purpose:	To document voluntary participation in the Research program.
Routine Uses:	The SSN and home address will be used for identification and locating purposes. Information derived from the project will be used for documentation, adjudication of claims, and mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State, and local agencies.
Disclosure:	The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this data collection.

Part A • Volunteer agreement affidavit for subjects in approved Department of Army research projects

Note: Volunteers are authorized medical care for any injury or disease that is the direct result of participating in this project (under the provisions of AR 40-38 and AR 70-25).

Title of Research Project:	Title: Effects of Information Presentation Modality on Soldiers' Ability to Use the Information Effectively	
Human Use Protocol Log Number:	ARL--	
Principal Investigator(s):	Orest Zubal US Army Research Laboratory Human Research and Engineering Directorate	Phone: (410) 278-5841 E-Mail: zubal@arl.army.mil
Associate Investigator(s)	David Scribner US Army Research Laboratory Human Research and Engineering Directorate	Phone (410) 278-5983 E-Mail dscribne@arl.army.mil
	Christopher Stachowiak US Army Research Laboratory Human Research and Engineering Directorate	Phone (410) 278-4397 E-Mail cstachow@arl.army.mil
Location of Research:	Aberdeen Proving Ground	
Dates of Participation:	August 2004	

I do hereby volunteer to participate in the research project described in the table above. I have full capacity to consent and have attained my 18th birthday. The implications of my voluntary participation, duration, and purpose of the research project, the methods and means by which it is to be conducted, and the inconveniences and hazards that may reasonably be expected have been explained to me. I have been given an opportunity to ask questions concerning this research project. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights or project related injury, I may contact the **ARL-HRED Human Use Committee Chairperson at Aberdeen Proving Ground, Maryland, USA by telephone at 410-278-0612 or DSN 298-0612.** I understand that any published data will not reveal my identity. If I choose not to participate, or later wish to withdraw from any portion of it, I may do so without penalty. I understand that military personnel are not subject to punishment under the Uniform Code of Military Justice for choosing not to take part as human volunteers and that no administrative sanctions can be given me for choosing not to participate. I may at any time during the course of the project revoke my consent and withdraw without penalty or loss of benefits. However, I may be required (military volunteer) or requested (civilian volunteer) to undergo certain examinations if, in the opinion of an attending physician, such examinations are necessary for my health and well being.

Date of preparation of current version: 12 July 2004
Expiration Date: 30 June 2005 Volunteer Initials_________ Administrator Initials_______

ID#______

Part B • To be completed by the Principal Investigator

Note: Instruction for elements of the informed consent provided as detailed explanation in accordance with Appendix C, AR 40-38 or AR 70-25.

Purpose of the Research

You are being invited to participate in a study designed to evaluate different techniques for presenting information and the effect the various presentation methods has on you performance and workload. During this study you will assume the role of a vehicle (Bradley Fighting vehicle, M1 Tank, etc.) and we will compare the effects giving you information by different methods: visual, tactile, and auditory, while you attend to a video war game and direct your vehicle and provide surveillance and security on the way to your destination. This study is part of the Army Research Laboratory's of the Science and Technology Objective on Situational Understanding examining different developing technologies for presenting information to soldiers.

Procedures

You will be assigned a participation number and will be asked to complete a demographics questionnaire.

You will wear your normal uniform. You may have to remove your BDU top.

You play the role of a vehicle commander and a squad leader. You will practice playing a computer war game until in which you will act as the vehicles commander/gunner and provide security surveillance. You will be afforded several practice runs until you feel that you can operate the vehicle controls in the game. Once you're comfortable playing the game you will be issued a belt that you will wear around your waist, and a set of earphones. There are three portions in this effort. One portion will require you to use information on a video screen and issue short orders using a command screen. A second portion will require you to pay attention to the vibrating belt and use its information to develop orders on the command screen. A third portion will present information through your earphones and you will develop orders on the command screen.

You will be playing the computer game as if you were the commander of the vehicle in that game. You will also function as a squad leader and respond to requests from the other vehicles in your squad. As the vehicle commander/gunner you will have to provide tithe surveillance security for your vehicle. As you travel to your destination you must be vigilant to detect and destroy enemy targets that may otherwise hurt or destroy your vehicle. But also remember that the other three vehicles under your command in the squad are dependent on you to provide the direction they must travel to get to the next waypoint or get out of harm's way. So you must attend to providing security for you own vehicle and quickly providing the required information so that all the vehicles in your squad get safely to their destinations. You will have to respond to only one of the methods (screen, belt, or earphone) during a test run. Before each test run you will receive practice receiving and understanding the information being

present so that you can issue the proper orders.

After you complete each test run you will be asked to fill out a short questionnaire rating the level of effort during that run.

After completing all three test runs you will be asked to fill out a final questionnaire rating the overall test.

Total time required to complete game familiarization, training to use the different systems, performing the three test runs should require approximately 2 to 2 ½ hours. Breaks are always available at your request.

Benefits

You will receive no benefits for participating in this effort, other than the personal satisfaction of support research efforts in the development of alternative systems for presenting information to vehicle commanders.

Risks

Risks associated with this effort are minimal. They are not unlike those that face computer users or computer gamers. Symptoms such as headaches and eye strain may be associated with extended video viewing. You may ask for a break any time; but, you will get a break between train sessions and test run sessions.

Confidentiality

All data and information obtained about you will be considered privileged and held in confidence. Photographic or video images of you taken during this data collection will not be identified with any of your personal information (name, rank, or status). All examinations will be recorded using a volunteer identifier code and a separate file with your consent form and the Principal Investigator will keep your assigned volunteer identifier code in a locked cabinet. Complete confidentiality cannot be promised, particularly if you are a military service member, because information bearing on your health may be required to be reported to appropriate medical or command authorities. In addition, applicable regulations note the possibility that the U.S. Army Medical Research and Materiel Command (MRMC-RCQ) officials may inspect the records.

Date of preparation of current version: 12 July 2004
Expiration Date: 30 June 2005 Volunteer Initials_________ Administrator Initials_______

ID#______

Disposition of Volunteer Agreement Affidavit

The Principal Investigator will retain the original signed Volunteer Agreement Affidavit and forward a photocopy of it to the Chair of the Human Use Committee after the data collection. The test administrator will provide a copy to the volunteer.

Your signature below indicates that you: (1) are at least 18 years of age, (2) have read the information on this form, (3) have been given the opportunity to ask questions and they have been answered to your satisfaction, and (4) have decided to participate based on the information provided on this form.

<table>
<tr><td colspan="2">***Printed Name of Volunteer (First, MI., Last)***</td></tr>
<tr><td>***Social Security Number (SSN)***</td><td rowspan="2">***Permanent Address of Volunteer***</td></tr>
<tr><td>***Date of Birth
(Month, Day, Year)***</td></tr>
<tr><td>***Today's Date
(Month, Day, Year)***</td><td>***Signature of Volunteer***</td></tr>
<tr><td colspan="2">***Signature of Administrator***</td></tr>
</table>

Contacts for Additional Assistance

If you have questions concerning your rights on research-related injury, or if you have any complaints about your treatment while participating in this research, you can contact:

Chair, Human Use Committee
U.S. Army Research Laboratory
Human Research and Engineering Directorate
Aberdeen Proving Ground, MD 21005
(410) 278-0612 or (DSN) 298-0612

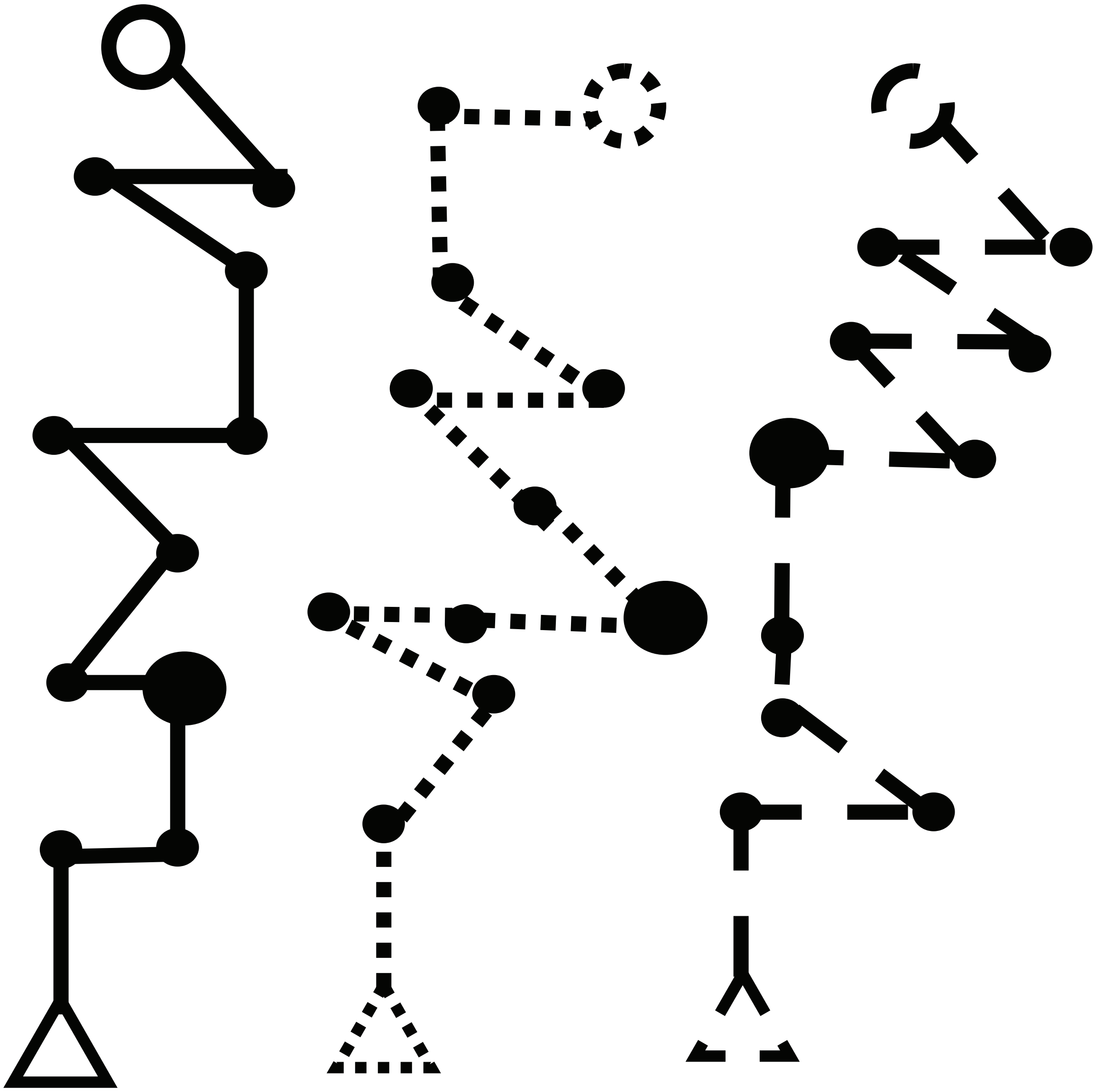
OR

Office of the Chief Counsel
U.S. Army Research Laboratory
2800 Powder Mill Road
Adelphi, MD 20783-1197
(301) 394-1070 or (DSN) 290-1070

Date of preparation of current version: 12 July 2004
Expiration Date: 30 June 2005 Volunteer Initials_________ Administrator Initials_______

Appendix C. Vehicles' Paths

Representation of Paths to be followed during the Training and Test Phases



The above generic paths represent routes to be taken by three separate vehicles, the characteristics of the paths are:

Starting points are identified by the triangles
Waypoints are identified by small dots
Location of the vehicle is at the large dot
End point is at the last large "empty" dot

The actual paths to be used in the effort will be such as to be compatible with the background topography and feature start and end points and ten intermediate waypoints.

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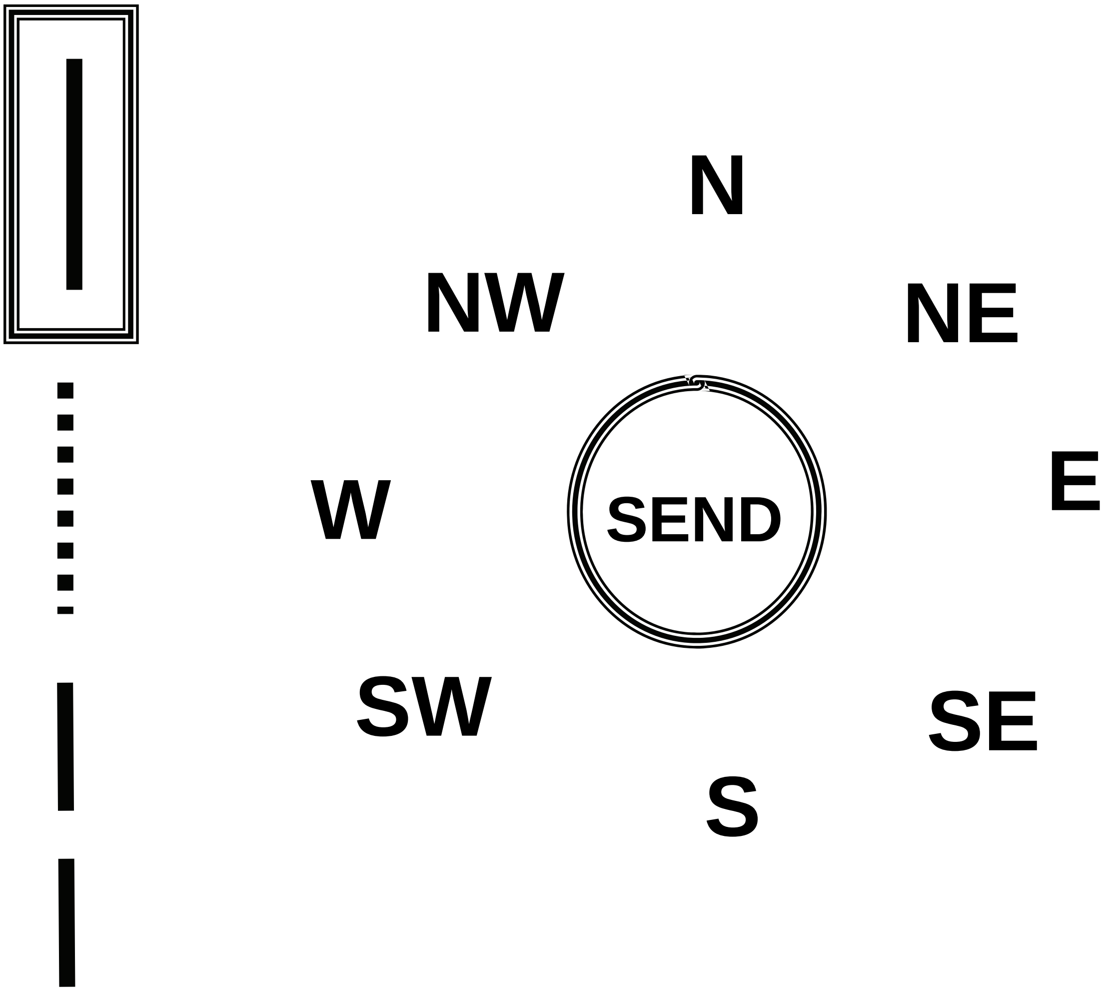
Appendix D. Command Screen

Command Screen Available for Sending Course Direction to the Vehicle in Question



The command screen that the participant will use to set and send the directional data to the requesting path.

Along the left are the paths that are displayed on the separate topographic screen. The path requesting the directional update is highlighted by the box.

The participant can determine the appropriate direction, using either visual, tactile, or auditory method and select the compass direction and activate the send button.

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Appendix E. NASA TLX Rating Scale and Definitions

MODALITY:______________________ DATE_____________ **ID#______**

TLX Workload Scale

Please rate your workload by putting a mark on each of the six scales at the point which matches your experience.

Mental Demand

Low **High**

Physical Demand

Low **High**

Temporal Demand

Low **High**

Performance

Good **Poor**

Effort

Low **High**

Frustration

Low **High**

TLX Rating Scale Definitions

Rating Scale Title	Description
Mental Demand	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	How hard did you have to work (mentally and physically to accomplish your level of performance?
Frustration	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Appendix F. Results of the Demographic Questionnaire

				Age		SER VICE			Time in Rank			Time In MOS	
No.	DOB	Date	Yrs.	Yrs	Mo	Yrs	Mo	Ra nk	Yrs	Mo.	MOS	Yrs	Mo.
1	19781013	20050317	26	26	5	7	6	E6	2	1	19K	7	6
2	19720928	20050318	32	32	6	11	8	E6	11	8	63M	N/A	N/A
3	19730706	20050318	31	31	8	12	2	E6	4	0	63M	12	2
4	19850213	20050318	20	20	1	1	6	E4	0	2	19D	1	6
5	19820708	20050318	22	22	8	3	1	E5	1	1	19K	3	9
6	19761201	20050322	28	28	3	9	2	E5	5	6	92Y	9	8
7	19790823	20050322	25	25	7	2	6	E5	0	6	19D	1	8
8	19761002	20050323	28	28	7	6	7	E5	1	0	11B	6	7
9	19730828	20050324	31	31	7	12	11	E6	2	0	11B	12	11
10	19660203	20050324	39	39	1	13	5	E5	6	0	19K	N/A	N/A
			AVG	28.2	5.3	7.6	5.4		3.2	2.4		6.4	7.1
			S.D.	5.45	2.71	4.48	3.06		3.43	3.06		4.47	2.64

Ranks	E4	1
	E5	5
	E6	4

	Second		Time In Pos.		Han ded			Glasses	
No.	MOS	Duty Poss.	Yrs	Mo	L	R	Waist	Y	N
1	None	Instructor	1	1		X	40		X
2	4ST	Drill Sgt	3	0		X	34		X
3	None	Sys Maint	12	2		X	33	X	
4	None	Scout	0	2		X	36	X	
5	None	TC/Instructor	0	8		X	32		X
6	None	Suply Sgt.	5	6		X	34		X
7	None	Instructor	1	8		X	34	X	
8	None	Infantry	6	7		X	35		X
9	None	Inf Drl Sgt	1	0		X	34		X
10	None	TC/Instructor	6	0		X	34	X	
		AVG	3.5	3.4			34.6		
		S.D.	3.81	3.44			2.17		
							Glasses	4	6

	Use Puter		Play	Gam	Per	Use In Play				Vehicle			Position			
No.	Work	Home	Y	N	Day	Mouse	KeyB	Joy	Othr	Brad	M1	Othr	C	G	L	D
1		X	X		30	X	X				X		X	X	X	X
2	X	X	X		120	X	X			X	X			B		B/M1
3	X			X	0					X	X			B		B/M1
4		X		X	0					X						X
5		X		X	0						X		X	X	X	X
6	X	X		X	0					N/A						
7	X	X		X	0					X		HMMMV				B/H
8		X	X		120	X	X			N/A						
9		X	X		30	X	X	X	A	N/A						
10	X	X		X							X		X	X	X	X

A Thrumaster FCS with Paddles

	Education						
No.	GED	High S	Some COL	BS	MS	PHD	Other
1			X				
2			X				
3		X					
4		X					
5		X					
6		X					
7	X						
8		X					
9		X					
10			X				

No.	Training Specialty
1	HAZMAT, Instructor Course
2	Automotive Tech
3	None
4	None
5	None
6	None
7	None
8	None
9	SOTIX Course, Airborne, Air Assault, Drill Sergeant Course, ILRP course, Patrol & Advanced
10	None

Appendix G. Results of the NASA TLX Questionnaire

Table G-1. NASA TLX ratings of the different systems

Participant	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Visual										
Mental	4.0	6.0	0.0	2.0	5.5	9.0	4.0	8.0	6.5	7.0
Physical	1.0	6.5	0.0	0.5	0.0	6.0	0.0	8.5	4.5	2.5
Temporal	5.0	8.0	5.0	0.5	4.0	5.0	1.0	8.5	6.0	5.5
Performance	4.0	1.5	7.5	1.0	2.0	6.0	5.0	8.5	6.0	5.5
Effort	5.0	5.0	5.0	1.0	5.5	8.0	2.5	8.5	6.0	6.0
Frustration	2.0	3.0	5.5	0.5	4.5	5.0	0.0	9.0	5.5	5.5
									AVG	4.5
									S.D.	2.69
Auditory										
Mental	5.0	9.5	4.5	5.5	6.0	9.0	4.0	8.5	6.5	7.0
Physical	2.0	4.0	0.5	1.5	0.0	6.0	0.0	8.5	4.5	4.5
Temporal	6.0	8.0	3.5	5.0	5.0	7.0	2.0	8.5	5.5	5.0
Performance	3.0	4.0	7.5	1.0	5.0	6.0	4.0	8.5	6.0	5.0
Effort	7.0	7.0	5.0	5.0	7.0	8.0	0.5	8.5	6.0	5.5
Frustration	7.0	1.5	5.0	4.0	5.5	6.5	3.0	8.5	5.5	6.5
									AVG	5.3
									S.D.	2.38
Tactile										
Mental	3.0	2.5	2.5	4.5	5.0	7.0	1.0	2.0	4.0	6.5
Physical	3.0	2.5	0.0	4.0	0.0	6.0	0.0	2.0	3.0	6.0
Temporal	2.0	3.0	2.5	3.5	3.5	5.0	0.0	2.0	6.0	5.5
Performance	7.0	0.5	6.5	1.0	5.5	7.0	9.0	3.5	7.5	7.5
Effort	2.0	4.5	2.0	5.5	3.0	7.0	1.0	1.5	4.5	6.5
Frustration	3.0	2.0	1.5	4.5	5.0	2.5	0.0	2.0	4.0	5.0
									AVG	3.7
									S.D.	2.27

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